NASA TT-11,397

NASA TT-F-11,397
TT-F-11

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Translation of "Dal'neyshiye issledovaniya kompleksnogo vozdeystviya na organizm ioniziruyushchego izlucheniya i uskoreniy v svyazi s kosmicheskimi poletami." Report at the Eighteenth Congress of the International Astronautical Federation, Belgrade, 25-30 September 1967

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON DECEMBER 1967

FURTHER INVESTIGATIONS OF THE COMPLEX EFFECT OF IONIZED RADIATION AND ACCELERATIONS ON THE ORGANISM AS RELATED TO SPACE FLIGHTS 1 *

V.V. Antipov, B.I. Davydov, E.F. Panchenko, P.P. Saksonov

In connection with the development and use of a system of measures to provide safety against radiation during space flights, there has been heightened interest recently in the study of justification of permissible doses of ionizing radiation for the crew members of space ships.

As we know, the magnitude of permissible dosage, the criterion of radiation danger, has a specific influence on the design of the ship, flight program, it regulates the use of radiation protective means, etc. Therefore it is understandable that radiobiologists strive to substantiate comprehensively the recommended irradiation doses, with maximum consideration of space flight specifics.

Wt the present time a number of authors (G.M. Frank, P.P. Saksonov, V.V. Antipov, N.N. Dobrov, 1962; V.V. Antipov, N.N. Dobrov, P.P. Saksonov, 1964; Yu.G. Grigor'yev, Ye.Ye. Kovalev, A.V. Lebedinskoy et al, 1965; and others) propose various permissible levels of irradiation for the crew of space ships in brief and prolonged flights. The recommendations made in these works, in spite of their differences, stress two very important circumstances. First, determination [substantiation] of recommended dosage must be made with due consideration of the radiation conditions, depending on the duration of the space flight. Second, the proposed permissible levels of radiation must be defined, and for this special studies must be made. This applies first of all to the dosage recommended 2
during prolonged flights.

The problem of evaluating permissible irradiation doses during exposure to space flight factors is presented in a new and unusual aspect. In determining these levels it is necessary to take into consideration the fact that the organism is exposed to the complex effect of radiation and other factors during space flights, and consequently, one must be governed first of all by the fact of tolerance of various extreme factors related to flight by the irradiated organism.

Along with the study of the combined effect of ionizing radiation and other factors of great importance in this aspect are works directed toward defining and determining the values of RBE [relative biological effectiveness] of each component ofcosmic radiation, toward studying the long range sequelae of exposure to radiation.

It was demonstrated in several of our previous reports (V.V.

*Numbers in the margin indicate pagination in the original foreign text.

Antipov, V.G. Vysotskiy, B.I. Davydov et al, 1963; V.V. Antipov, B.I. 2
Davydov, E.F. Panchenkova et al, 1964; V.V. Parin, V.V. Antipov, B.I. Davydov, E.F Panchenkova, G.A. Chernov, 1964; V.V. Antipov, B.I. Davydov, E.F. Panchenkova, P.P. Saksonov, G.A. Chernov, 1965, and others) that the dynamic factors of flight alter substantially the organism's reaction to ionizing radiation. And the direction and magnitude of the changes are related to the nature and force of the stimulus, time and successiveness of action of the factors, form of object, etc. It seems to us that the importance of these facts for substantiation of maximum permissible irradiation levels for cosmonauts is obvious.

The present report submits data which are a further development of
our studies of the reactivity of the irradiated organism and effect of 3
various flight factors. In particular, an effort is made to evaluate the role of recovery processes in the irradiated organism in its reaction to critical accelerations. In addition some views are expressed regarding the possibility, in principle, of extrapolating experimental data on man and of obtaining tentative data on permissible irradiation doses evaluated by the criterion of acceleration tolerance.

Experiments were conducted on 1200 albino mongrel male mice which were exposed to gamma or x-rays in doses of 100-4000 (15-18 r/min) rem* [roentgen equivalent, man]. On the first to 45th post-irradiation day the animals were submitted for three minutes to accelerations of 44 g (30-50 second rise and drop). The material and method of investigation are described in greater detail in the works of V.I. Davydov, V.V. Antipov, P.P. Saksonov (1965, 1967).

Let us turn to presentation and discussion of the results obtained.

Earlier B.I. Davydov (1966) had demonstrated that animals' tolerance to accelerations (44 g) at different post-irradiation intervals was related to dosage and could be represented by a hyperbolic curve (Figure 1). On this figure, the dots designate data on the basis of which the curve was plotted. As seen in Figure 1, the segment of the curve, $1<t<9$, coincides rather well with the experimental value. It was then necessary to verify the validity of this curve for more advanced stages of radiation sickness, as well as to obtain additional experimental data on the animals' tolerance during the first post-irradiation day. The initial
segment of the curve on Figure 1 implies that the mice tolerate accelera- 4
tions at a dosage of about 4000 rem. It may be considered with some degree of certainty that any point in the hash-marked part of Figure 1 will reflect tolerance of accelerations by irradiated animals that is greater or equal to that of the control. For example, following irradiation in doses of 2000 and 4000 rem tolerance of accelerations on the

*0.75 is used as the RBE for gamma rays (S.P. Yarmonenko, A.G. Konoplyannikov, 1965).

first postirradiation day should be the same as in the control or some- 4
what greater. The studies performed revealed that irradiated animals presented greater tolerance of accelerations than control mice: 0.86 and 0.58 respectively at 2000 and 4000 rem.

After repeated centrifugation the death rate among irradiated animals was 50% at 2000 rem and 70% at 400 rem. It is known (B. Rzevskiy, 1959) that the mean survival of mices at doses of 1500-15000 rem is 3.5 days. At doses over 15000 rem the mean survival time begins to drop rapidly with increase in irradiation dosage. It may be assumed that tolerance of accelerations at t<1 will remain within the control range at does of 10000-15000rem.

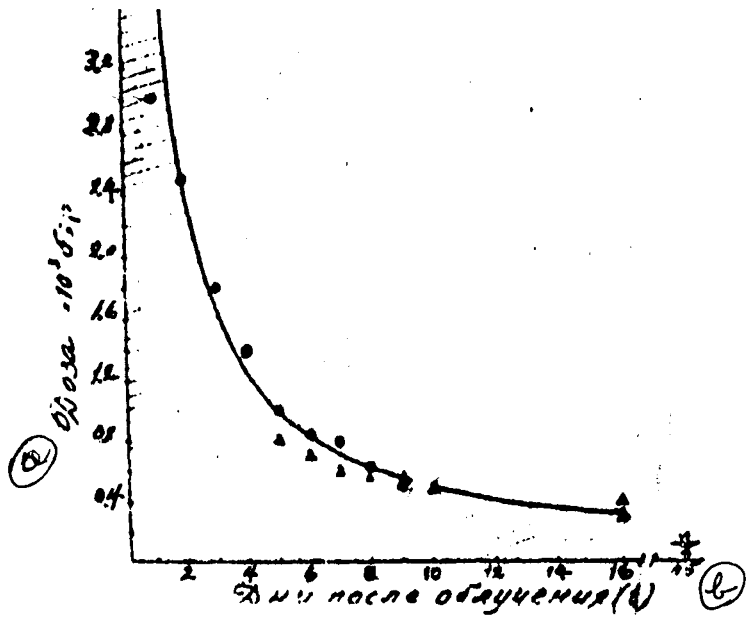

Figure 1. Dose-time relation of tolerance of irradiated mice of accelerations 14

Legend:
- • -- single centrifugation
- Δ -- twofold centrifugation

a) dose $\cdot 10^3$ rem
b) days after irradiation (t)

4

As stated above, the curve on Figure 1 was obtained by determination of the threshold of tolerance of accelerations for nine days after irradiation. It was necessary to verify experimentally the segment of the curve for t>9 days after irradiation.

Animals exposed to doses of 100, 200, 350 rem were submitted to accelerations on the 45th day, and those exposed to doses of 300 and 500 rem — on the 16th post-irradiation day. Determination was made of doses at which the effect in experimental animals equalled the effect in the

control. Of course in determining tolerated irradiation dosage a cer- 4
tain assumption was made regarding linear relation of the animals' reaction to accelerations to magnitude of irradiation doses in the inter-
vals of tested doses. As it is known, at earlier postirradiation inter- 5
vals, this relation [function] is more complex (B.I. Davydov, V.V. Antipov, P.P. Saksonov, 1965). On the 16th and 45th post-irradiation days, at doses of 481 and 150 rem tolerance of accelerations corresponded to the control.

Thus the experimental data obtained indicate that the degree of resistance to accelerations was related to irradiation dosage. This relation may be presented as a hyberbolic curve equation: $Dt = 5.10^3$ (1), where D is the dosage in rem; t is postirradiation time, in days.

Analysis of the available data revealed that there are common patterns in the reactions of irradiated animals to extreme accelerations and repeated irradiation. There are periods of reduced and increased sensitivity of irradiated animals to accelerations and repeated irradiation. The period of increased resistance to accelerations is 8-9 days at doses of 250-500 rem, according to our data. The period of increased radioresistance (11-12 days) determined by the repeated irradiation test corresponds to 12-15 days (I.G. Akoyev, M.A. Lagun, 1964).

Some authors (S.N. Aleksandrov, K.F. Galkovskaya, 1963) observed increased or normal resistance of mice to strychnine, novoembichin, Ehrlich's tumors, even 50-65 days after irradiation. This contradicted the theory of H. Blair (1962) as to the presence of an irreversible component in radiation lesions.

Our data, on the contrary, indicate that on the 45th postirradiation day there is reduced resistance to accelerations, which is indicative of the presence of an irreversible component in the radiation lesion detectable by this test.

Let us now try to evaluate tolerance of irradiated animals of
repeated exposure to critical accelerations. This is of interest in 6
determining tolerated doses by the multiple exposure test. There is no doubt that each new exposure alters the animal's reactivity, therefore it is interesting to learn how and in what direction the reaction changes in response to repeated exposure to the same factor. Thus exposure to accelerations at a specific interval of time after the first centrifugation would be a test index of reactivity of the surviving animals.

It may be assumed that the reaction of irradiated animals to repeated centrifugation is a function of the period [stage] of radiation sickness.

If A_0^1 and A_0^2 represents percentile death in the control, and A^1 and A^2 -- death rate among irradiated animals during first and second centrifugation, respectively, then $A^1/A_0^1 = K_1$ is the index of tolerance of the first acceleration and $A^1/A^1_0 = K_1$ -- of exposure to the second. With $K<1$, the tolerance of irradiated animals is higher, and with $K>1$ it is lower. 6

The curves shown on Figure 2 for doses of 250 and 500 rem represent K_1/K_2 at different postirradiation days and they were obtained from processing Figure 1. As shown in Figure 2, on the 4th-7th postirradiation days, $K_1/K_2 <1$, i.e. the irradiated animals show lower tolerance upon repeated accelerations than at the first exposure. At all other intervals the reverse is true: increased resistance of irradiated animals to the second centrifugation, as compared to the first. At a dosage of 100 rem, K_1/K_2 shows negligible difference from 1, therefore it may be considered that at a dosage of 100 rem the animals react to the second centrifugation just like the controls.

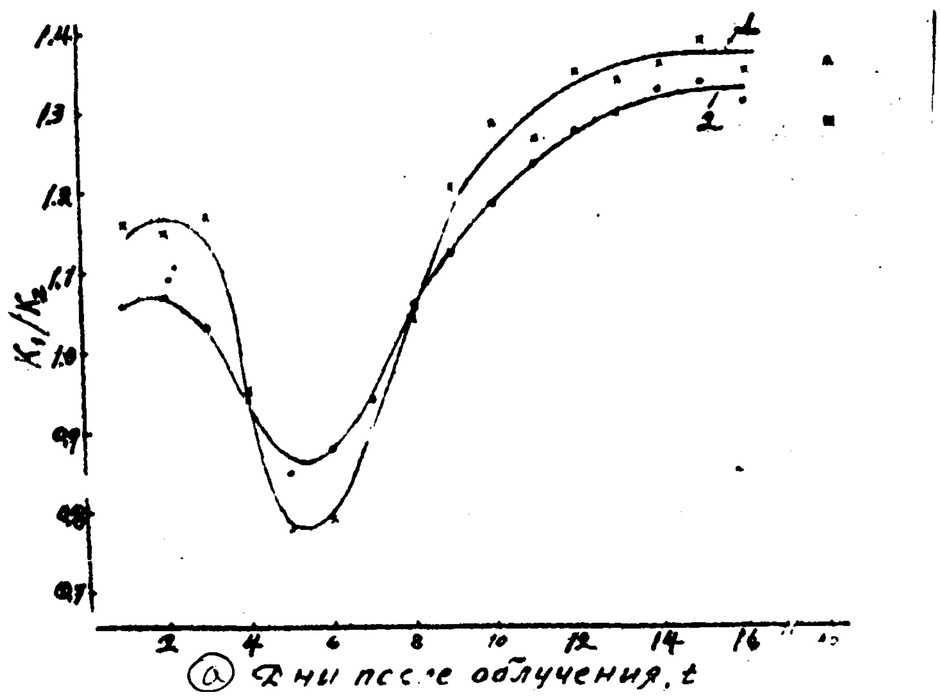

Figure 2. Change in reactivity of irradiated mice to repeated centrifugation 14

Legend:

a) days after irradiation, t

$K_1 = A^1/A^1_0$, $K_2 = A^2/A^2_0$

A^1 -- death of experimental animals, %, A^1_0 -- death of control animals, %, with first centrifugation.

A^2 -- death of experimental animals, %, A^2_0 -- death of control animals, %, with second centrifugation

1) 500 rem ▲) 350 rem ■) 200 rem o) 100 rem

2) 250 rem

In addition we determined tolerance doses of irradiation for animals with two-fold centrifugation. The results obtained are shown in the form of triangular symbols on Figure 1. As we see in this figure, the permissible irradiation dosage with twofold centrifugation is somewhat smaller than with single exposure to accelerations. At $t \geqslant 5$ the data on tolerance of irradiated animals for repeated accelerations can be approximately described by an exponential function: $D = D_0 1^{-dt}$, where D is the dose in rem; D_0 is the initial dose, r; t is the time after irradiation in days; e is the base of the natural logarithm, d is the coefficient. Processing by the method of least squares resulted in the regression equation: $\lg D = 2.993 - 0.065 \cdot t \cdot \lg e$; $(t \geqslant 5)$ (2). 6 7

Let us try to extrapolate the experimental data obtained to man.

Previously (B.I. Davydov, V.V. Antipov, P.P. Saksonov, 1965) on the basis of comparison of curves of mouse reactions to tolerance for accelerations and dynamics of drop in postirration leukocyte drop with a dosage of LD_{50} in man and animals, an effort was made to evaluate the period of half-restoration of normal reaction to accelerations.

The periods of half-restoration of radioresistance, estimated by the method of repeated irradiation and tolerance of extreme accelerations for mice, differ little from one another and for a dosage of about LD_{50} constitute about five days in both cases (B.I. Davydov, V.V. Antipov, P.P. Saksonov, 1965). For man, the period of half-restoration was estimated at 25-35 days, which is consistent with the data of author authors (G.O. Devidson, 1960), obtained by another method.

However, it must be noted that only the half-period of low sensitivity of irradiated animals to extreme acceleration coincides with the period of half-recovery as estimated by the repeated irradiation test.

Before plotting the curve of man's tolerance for extreme accelerations at different irradiation doses, an effort should be made to choose the appropriate criteria to obtain extrapolation coefficients. One of the criteria that may be used to obtain an extrapolation coefficient may be the difference in radiosensitivity of animals and man. On the basis of data on $LD_{50/30-60}$ the mouse/man coefficient of radiosensitivity accoridng to mortality was found to average 1.35 for mortality probability levels of 0.1 -- 95%. 8

In our preceding studies (B.I. Davydov, V.V. Antipov, P.P. Saksonov, 1965) it was established that the curve of tolerance for accelerations in irradiated mice correlates with the mean life span (MLS) of irradiated mice. It could be believed that this correlation remains valid for man. Indeed, the period of normal (or low) sensitivity of the irradiated organism to accelerations cannot exceed the MLS.

In view of the differences in MLS following irradiation in man and

mice, coefficients of extrapolation from animals to man were obtained for 8
doses of 300-2000 rem. For doses of 300-600, 700-900 and 1000-2000 rem these coefficients constituted 1.77(1.72 – 1.88), 2.00 (1.95 – 2.05), and 2.50, respectively. Taking this coefificent into consideration at 300-2000 rem equation 1 will have the appearance of $Dt = 5 \cdot 10^3 C$, where $C_{300-600}$ rem = 1.77; $C_{700-900}$ rem = 2.00; C_{1-2} krem = 2.50, and with consideration of a coefficient of radiosensitivity = 1.35 we will have $Dt = 3.7 \cdot 10^3 \cdot C$; (200 rem < D $\leq$ 700 rem. (3).

For doses under 200 rem, when the probability of death is only 1-3%, according to the data of Langham et al (W. Langham, Ph. Brooks, D. Grahn
et al, 1965), it is apparently purposeless to use the coefficient of 9
extrapolation obtained on the basis of MLS of animals that died.

In our opinion, at doses under 200 rem it is more purposeful to use the criterion of difference in rate of recovery processes. It is known that the rate of recovery processes in the presence of radiation lesions correlates with the rate of metabolic processes and, consequently with the animal species.

According to the data of a number of authors, the periods of half-recovery of radiosensitivity in man and mice constitute 25-35 and about 5 days, respectively. Devidson (1957) determined the mean half-recovery time for man at about 28 days; according to the criterion of tolerance of extreme accelerations our data show it to constitute about 26 days (B.I. Davydov, V.V. Antipov, P.P. Saksonov, 1965). The ratio of man/mouse half-restoration period will be 6.5-5.2.

As seen in Figure 1, 45 days after irradiation, with a dosage of 100 rem, tolerance of accelerations will be the same as in the control. This period is greater than the period of total recovery from radiation lesions in the mouse. In man the period of total recovery from the reversible component of radiation lesion is estimated at 200 days. Consequently, in this case the ratio of man/mouse periods of total recovery will be about 4.4. Coefficients obtained by different means are rather close. The mean coefficient will be about 5. For a dosage of 200r, equation 3 will have the following appearance: $Dt = 1.85 \cdot 10^4$; (D $\leq$ 200 r). In equation 2, which describes the reaction of the irradiated animal to repeated centrifugation, one must also interpolate the corresponding extrapolation coefficients in order to obtain the tolerance curve for
irradiated man for a second exposure to accelerations. 10

Figure 3 presents several curves obtained by extrapolation of experimental data to man (B.I. Davydov, V.V. Antipov, P.P. Saksonov, 1967). Curve 3 on this figure gives an idea about normal human tolerance of accelerations after exposure to irradiation in doses of 200-700 rem, and curve 4 -- at a dosage of 200 rem. However the time of the primary reaction must be taken into consideration. Thus, according to the literature summarized in the work of Yu.G. Grigor'yev et al (1965), a marked primary reaction at doses up to 400 rem persists up to three days. The probability of appearance of primary reaction is related to irradiation dosage. Curve "c" on Figure 3, obtained from the data of W.C. Brown (1953, 1953a, 1955), H. Gerstner (1960), J. Morton (1957), L. Miller, G. Fletcher, H. Gerstner (1958), J. Burwell, H. Wolfson, C. Perryman, F. Foldes (1961), and curve "b" according to Yu.G. Grigor'yev et al (1965) gives an idea about this relationship. These curves differ from one another. This is apparently related to the fact that the former data were obtained essentially on humans irradiated as the result of accidents, while the latter were obtained in cases of therapeutic irradiation of sick individuals. 10

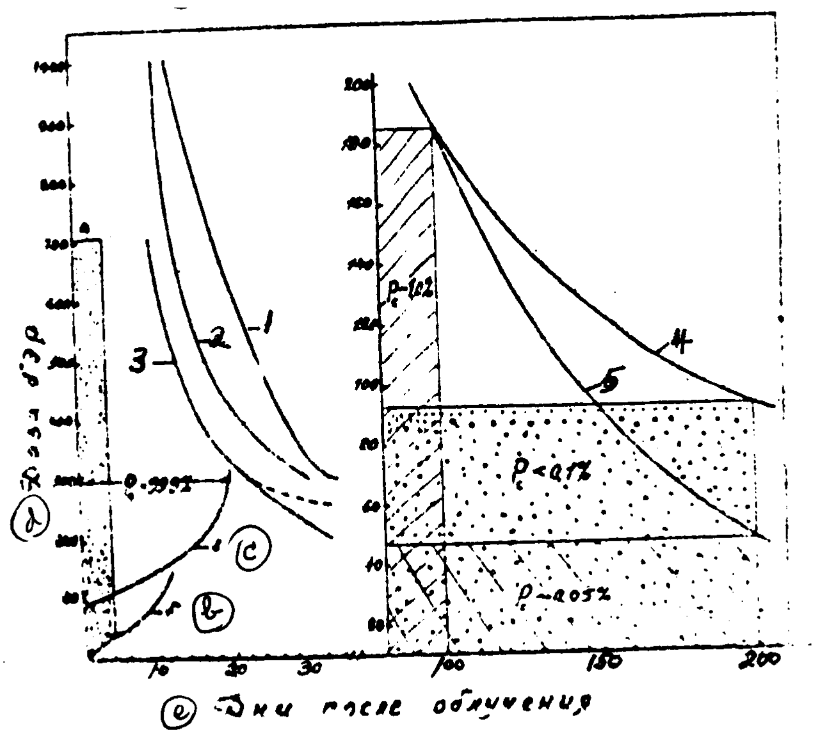

Figure 3. Theoretical dose-time relation of critical acceleration tolerance of irradiated humans 14

Legend:

1) mean life span (MLS) of individuals who died after irradiation
2) extrapolated curve of human tolerance of accelerations (extrapolation coefficient by MLS)
3) the same as curve 2 with consideration of radiosensitivity coefficient
4) acceleration tolerance curve (single exposure) for man at doses under 200 rem
5) the same as 4 (twofold exposure)
a) maximum period of primary reaction
b) probability of primary reaction (P_n %) according to Yu.G. Grigor'yev et al (1965)
c) the same as "b" (at 300 rem, P_n = 99.9%) according to Kurt Braun (1953, 1955), Gerstner (1960) and others. 15

P_o) probability of death in man   d) dosage, rem   e) days after irradiation

As seen in Figure 3, the irradiation dosage is functionally related 10
to the time that has elapsed after irradiation. In order to determine
the irradiation dosage at which acceleration tolerance will be normal,
it is necessary to determine the time that could be taken as the final
point on the abscissa on Figure 3. Consequently it is necessary to
choose criteria that would determine this point. As the ultimate point
on the abscissa of Figure 3, with some allowances, we can take the inter-
val equal, in the first place, to the first half of the period of total
postradiation recovery during which there is compensation of 90% of the
reversible component of the radiation injury, and in the second place,
to the period of total recovery. The period of total recovery from radia- 11
tion injury estimated by recovery of radiosensitivity constitutes 200 days.

On curve 4 (Figure 3) the minimum permissible irradiation dosage that will not elicit changes in reactivity of the organism to acceleration (one exposure) for 200 days will constitute about 90 rem. For the second centrifugation this dosage will be about 50 rem (curve 5).

Consequently, on the basis of our data, which were obtained by extrapolation, it may be considered that at doses of 50-90 rem human tolerance of accelerations after exposure to such doses will apparently not differ appreciably from that of healthy individuals for a period of 200 days after irradiation.

As was already stated in the beginning of this report, the problem of substantiation of permissible doses of ionizing radiation for the crew of flying machines was raised in a series of works (G.M. Frank, P.P. Saksonov, V.V. Antipov, N.N. Dobrov, 1962; V.V. Antipov, N.N. Dobrov, P.P. Saksonov, 1964; Yu.G. Grigor'yev, Ye.Ye. Kovalev, A.V. Lebedinskiy, Yu.G. Nefedov, 1965; Yu.G. Grigor'yev, A.K. Gus'kova, M.P. Domshlak, V.G. Vysotskiy et al, 1965). However in most cases the criteria used by the authors to estimate the permissible doses were inadequate factors of space flight.

For this reason it seemed of interest to try to develop some other
methods of estimating permissible doses, more specific for space flight
conditions. At the first stage, as one of the possible criteria we
selected acceleration which is one of the important factors of space
flight (V.V. Parin, P.V. Vasil'yev, V.Ye. Beley, 1965). 12

As seen from the material presented, estimation of permissible doses is made only on the basis of quantitative indices. However this is obviously not sufficient, and for deeper analysis it is evidently necessary to use some physiological, biochemical and other tests.

Using quantitative differences between radiobiological patterns in mice and man also tried to extrapolate the experimental data to man, while recognizing the arbitrariness of such a method. However, it must be noted that there is a similarity between some qualitative radiobiological shifts in mice and man. Thus, Mate (1962) indicates that the decrease in number of different blood cells in man occurs in the same chronological order as in mice: first the lymphocytes, then reticulocytes, granulocytes and, finally, thrombocytes. As stressed by P.P. Saksonov (1959), A.S. Mozzhukhin, F. Yu. Rachinskiy (1964), comparison of the clinical findings in acute radiation sickness in man and higher animals reveals that there are only quantitative differences in the manifestation of different symptoms as well as in the time of their development after irradiation. 12

Thus, the data submitted in this report should be interpreted as the first attempt to approach substantiation of permissible irradiation levels for cosmonauts from new positions. It is quite obvious that the final estimation of extrapolation coefficients given in this report will be obtained under actual flight conditions, however, to define them, even now 13
it would be purposeful to conduct a series of experiments on other animal species.

For the purpose of obtaining further data, to define the existing permissible levels of irradiation for cosmonauts and substantiate new levels, of great promise are studies in which other extreme flight factors will be used as evaluation criteria.

References 16

Akoyev, I.G., Lagun, M.A.: in the collection: Recovery Processes Related to Radiation Lesions (Vosstanovitel'nyye protsessy pri radiatsionnykh porazheniyakh), Atomizdat, 1964, p 96.

Aleksandrov, S.N., Galkovskaya, K.F.: Medical Radiology (Med.radiologiya) No 5, 1963, p 17.

Antipov, V.V., Vysotskiy, V.G., Davydov B.I. et al, in the book: Aviation and Space Medicine (Aviatsionnaya i kosmicheskaya meditsina), published by USSR Academy of Sciences, Moscow, 1963, p 23.

Antipov, V.V., Dobrov, N.N, Saksonov, P.P. in the book: Problems in Space Biology (Problemy kosmicheskoy biologii), 1964, 3, 113.

Antipov, V.V., Davydov, B.I., Panchenkova, E.F. et al: Journal of Space Research (Zh. Kosmicheskiye issledovaniya), 1964, 3, 5, 797.

Antipov V.V., Davydov, B.I., Panchenkova, E.F., Saksonov, P.P., Chernov, G.A., in the book: Proceedings of the 16th International Congress on Astronautics (Trudy XVI Mezhdunarodnogo Kongressa po Astronavtike), Athens, 1965, IV, 145.

Grigor'yev, Yu.G., Kovalev, Ye.Ye., Lebedinskiy, A.V., Nefedov, Yu.G. et al:Criterion of Radiation Safety of Prolonged Space Flights (Kriteriy radiatsonnoy bezopasnosti dlitel'nykh kosmicheskikh poletov), Reports to the Second International Congress under the title of "Man in Space" (Dokl. na II Mezhdunarodnom Kongresse pod devizom "Chelovek v kosmose"), Paris, 1965.

Grigor'yev, Yu.G., Gus'kova, A.K., Domshlak, M.P., Vysotskiy V.G., Rayevskaya, S.A., Markelov, B.A., Dorenskaya, N.P.: 16th International Astronautical Congress (XVI Mezhdunarodnyy Astronavticheskiy Kongress), Athens, 13-18 September 1965.

Davydov, B.I., Antipov, V.V., Saksonov, P.P.: Space Research (Kosmicheskiye issledovaniya), 1965, 3, 159. 16
Davydov, B.I., Antipov, V.V., Konnova, N.I., Saksonov, P.P.: Ibid, 1965, 5, 789.
Davydov, B.I.: Reports of the USSR Academy of Sciences (DAN SSSR), 1966, 168, No 3, p 691.
Davydov, B.I., Antipov, V.V., Saksonov, P.P.: in the collection: Problems in Space Biology (Problemy kosmicheskoy biologii), 1967, 6.
Mozzhukhin, A.S., Rachinskiy, F.Yu.: Chemical Prophylaxis of Radiation Lesions (Khimicheskaya profilaktika radiatsionnykh porazheniy), Atomizdat, 1964, 75. 17
Parin, V.V., Antipov, V.V., Davydov, B.I., Panchenkova, E.F., Chernov, G.A. in the book: Proceedings of the 15th International Congress on Astronautics (Trudy XV Mezhdunarodnogo Kongressa po Astronavtike), Warsaw, 1964, IV, 131.
Parin, V.V., Vasil'yev, P.V., Beley, V.Ye.: News of the USSR Academy of Sciences, Biology Series (Izvestiya AN SSSR, seriya biolog.), No 4, 1965, p 481.
Rayevskiy, B.: Radioactive Radiation Doses and their Effect on the Organism (Dozy radioaktivnykh izlucheniy i ikh deystviye na organizm), Medgiz, 1959.
Saksonov, P.P.: Brief Methodological Textbook on Experimental Pharmacotherapy and Prophylaxis of Radiation Lesions (Kratkoye metodicheskoye posobiye po eksperimental'noy farmakoterapii i profilaktike radiatsionnykh porazheniy), Voyenizdat, 1959.
Frank, G.M., Saksonov, P.P., Antipov, V.V., Dobrov, N.N.: First Intern. Symp. on Environmental Problem of Man in Space, Paris, 29 October -- 2 November 1962; 1965, 254, Springer-Verlag.
Yarmonenko, S.P., Konoplyannikov, A.G., in the collection: Problems in Space Biology (Problemy kosmicheskoy biologii), Nauka Press, 1965, 4, 139.
Blair, H.: Some Aspects Internal Irradiat., Oxford-London-New York-Paris, Perg. Press, 1962, 233.
Brown, W.C.: Brit.Med. J., 4814, 802, 1953.
Brown, W.C., Mahler, R.: Science, 1953, 118, 271.
Brown, W.C., Abbott, J.: Brit. J. Radiol., 1955, 28, 1953.
Burwell, J., Wolfson, B., Perryman, C., Foldes, F.: Am.J. Roentgenol. Rad. Therap., 1961, 86, 752.
Devidson, G.O.: 1957, Biological Sequelae of Total Gamma Irradiation of Man (Biologicehskiye posledstviya obshchego gamma-oblucheniya cheloveka), Atomizdat, 1960.
Gerstner, H.: Ann. Rev. Med., 1960, II, 289.
Langham, W., Brooks, Ph., Grahn, D. et al, Aerosp. Med., 1965, 36, 15.
Mate, Zh.: Medical Radiology (Med. radiologiya), 1962, No 2, 49.
Miller, L., Fletcher, G., Gerstner, H.: Radiation Res., 1958, 4, 150. 18
Morton, J.: Ann. Surg., 1957, 146, 314.